PERFORMANCE EVALUATION OF COATED CARBIDE AND COATED CERMET TOOLS WHEN TURNING HARDENED TOOL STEEL

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ABSTRACT

Hardened steel is widely used in the manufacture of dies, mould and automotive components such as bearings, gears and shafts. The continuous improvements and developments in cutting tool technology coupled with the availability of suitable machine tools have made it possible to machine steel in its hardened form thereby eliminating the heat treatment step, which is required in the conventional approach. Commercially available plastic mould steel, Stavax ESR, which is a premium grade stainless tool steel, has been hardened to (43 ~ 45 HRC) and turned using two commercially available cutting tool inserts with various side cutting edge angles and at various cutting speeds and feed rates. Turning was performed dry and a constant depth of cut was set. The cutting tool inserts used were a physical vapor deposition (PVD) multi coated TiCN based cermet grade with TiN inner layer, TiCN intermediate layer and a TiN outer layer (KT 315); and a cobalt enriched, multi coated carbide grade with thick moderate temperature chemical vapor deposition (MTCVD) - TiCN inner layer, an Al_2O_3 intermediate layer and TiCN and TiN outer layers (KC9110). Tool performance, tool failure modes and wear mechanisms of the said tools were investigated under various cutting conditions. The surface roughness of the turned part and the chip morphology were studied while the cutting forces were also measured. The performance of the cutting tools is described using response surface methodology. The cutting speed and feed are found to have an effect on the various responses investigated. Additionally, the side cutting edge angle is also found to provide secondary contribution to the tool life and surface roughness. The use of -5^{o} side cutting edge angle resulted in longest tool and better surface roughness. The mathematical models developed are statistically valid and sound, particularly for Fc. These are verified by the confirmation run experiments and therefore can be used for prediction within the limits of the factors investigated. KC 9110 outperformed KT 315 in terms of tool life for almost all of the cutting conditions tested. The only exception is at a low feed rate of 0.09 mm/rev and a low cutting speed of 100 m/min where the tool life of KT 315 was more than 30 minutes and this was the longest tool life achievable. For KT 315, flank wear and catastrophic failure are the dominant failure modes whereas for KC 9110 it was end clearance wear and flank wear. Flank and end clearance wear probably occur by both abrasive and adhesive wear mechanisms with abrasive wear being the major source of material removal. Catastrophic failure could be associated with a combination of abrasion, adhesion, diffusion, fracture and plastic deformation wear mechanisms. Saw-tooth chips are produced at almost all conditions with the exception of cutting at low cutting speed and feed. White layers are also detected on the chip underside.

ABSTRAK

Keluli yang telah dikeraskan digunakan dengan meluas dalam pembuatan dai, acuan serta komponen automotif seperti galas, giar dan aci. Pembaikan dan pembangunan berterusan dalam teknologi perkakas pemotong yang digabungkan dengan kebolehdapatan perkakas mesin yang sesuai telah membolehkan pemesinan keluli dalam keadaan keras dan ini dapat meniadakan langkah rawatan haba yang perlu dilalui jika pendekatan lazim diikuti. Keluli acuan plastik, Stavax ESR, yang diperolehi secara komersial, di keraskan ke 43 ~ 45 HRC dan dilarik menggunakan dua sisip perkakas pemotong, yang juga diperolehi secara komersial, pada pelbagai sudut pinggir-potongan sisi, laju pemotongan dan kadar uluran. Larikan dilakukan dalam keadaan kering dengan menetapkan ukur kedalaman pemotongan. Sisip perkakas pemotong yang digunakan ialah gred cermet berdasarkan TiCN yang disalut berlapis secara pengendapan wap fizikal (*physical vapor deposition, PVD*) dengan lapisan dalam TiN, lapisan pertengahan TiCN dan lapisan luar TiN (KT 315); dan gred karbida dengan diperkaya kobalt dan disalut berlapis secara pengendapan wap kimia pada suhu sederhana (*moderate temperature chemical vapor deposition, MTCVD*) dengan lapisan dalam TiCN, lapisan pertengahan Al_2O_3 dan lapisan luar TiCN dan TiN (KC 9110). Hayat alat, kaedah kegagalan dan mekanisma kehausan perkakas disiasat pada pelbagai keadaan pemotongan. Selain dari itu, moforlogi serpihan, daya pemotongan dan kekasaran permukaan juga diukur dan dikaji. Prestasi perkakas pemotong telah diterangkan menggunakan kaedah permukaan respon. Laju pemotongan dan kadar uluran didapati mempunyai kesan pada pelbagai respon yang disiasat. Sudut pinggir-potongan sisi juga didapati memberi sumbangan sekunder pada hayat mata alat dan kekasaran permukaan. Penggunaan sudut pinggir-potongan sisi -5^{o} memberikan hayat mata alat yang terpanjang dan kekasaran permukaan yang lebih baik. Model matematik yang dibangunkan didapati sah dan kukuh secara statistik, khususnya bagi Fc. Ini telah di sahkan oleh ujikaji pengesahan dan oleh itu boleh digunakan untuk ramalan. KC 9110 adalah lebih baik dari KT 315 dari segi hayat mata alat bagi hampir semua keadaan pemotongan yang diuji kecuali pada kadar uluran dan laju pemotongan rendah bersamaan 0.09 mm/rev dan 100 m/min masing-masing di mana hayat mata alat bagi KT 315 melebihi 30 minit dan ini merupakan hayat mata alat yang terpanjang yang dapat dicapai. Bagi KT 315, kehausan rusuk dan kegagalan bencana merupakan ragam kegagalan yang utama manakala bagi KC 9110 ia adalah kehausan kelegaan hujung dan kehausan rusuk. Kehausan rusuk dan kelegaan hujung berkemungkinan berlaku di sebabkan mekanisma kehausan lelasan dan rekatan dengan mekanisma kehausan lelasan merupakan punca utama pembuangan bahan. Kegagalan bencana boleh jadi berkaitan dengan kombinasi mekanisma kehausan lelasan, rekatan, resapan, kepatahan dan ubah bentuk plastik. Serpihan gigi gergaji diperolehi di hampir kesemua keadaan pemotongan kecuali pada laju pemotongan dan uluran rendah. Lapisan putih juga dikesan pada permukaan bawah serpihan.

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N_1	-	Spindle rotation with the rotating work material
n	-	Exponent depending mostly on tool material but is affected by work material, cutting conditions and environment
P_f	-	Heat generation in the region of secondary deformation (frictional heat rate)
P_m	-	Rate of energy consumption during machining or the total rate of heat generation
P_s	-	Rate of heat generation in the region of primary deformation (shear-zone heat rate)
R	-	Force applied to the chip at the tool-chip interface, nose radius
R^2	-	Coefficient of determination
R'	-	Resultant force on the chip applied at the shear plane
Ra	-	Arithmetical mean value
r	-	Cutting ratio or chip thickness ratio
SCEA	-	Side cutting edge angle
SR	-	Surface roughness
T	-	Tool life
t	-	Undeformed chip thickness or constant feed rate
t_c	-	Thickness of the chip
V	-	Cutting speed or work material velocity
V_c	-	Chip velocity
V_s	-	Shearing velocity
V_ω	-	Approach velocity
VB_B	-	Average width of the flank wear land
VB_N	-	Length of wear notch
VB_Bmax	-	Maximum width of the flank wear land
VC	-	Average width of the end clearance wear
$VCmax$	-	Maximum width of the end clearance wear
$x_1, x_2, \ldots x_i$.	-	Regressors or input variables
y_{est}	-	Estimated empirical variable

NOMENCLATURE

A	-	Cutting speed
A_a	-	Apparent area of contact
A_r	-	Real area of contact
A_S	-	Shear-plane area
B	-	Feed
b	-	Depth of cut
C	-	Constant depending on all input parameters, including feed or the Taylor constant, SCEA
C_e	-	End cutting edge angle
C_s	-	Side cutting edge angle
D	-	Diameter of the rotating work material
F	-	Friction force along the tool face
f	-	Feed
FI	-	Factor interaction
Fc	-	Main cutting force
F_N	-	Normal force perpendicular to the shear plane
F_P	-	Tangential force, force parallel to the velocity approach vector V_ω (i.e. the power contributing force)
F_Q	-	Feed force, force perpendicular to the finished work surface
F_R	-	Force perpendicular to F_P and F_Q
F_S	-	Shear force along the shear plane
h	-	Peak-to-valley height
h_{CLA}	-	Center-line-average value
i	-	Angle of inclination or angle of obliquity
K	-	Constant whose value lies between 0.9 and 1
KT	-	Depth of crater
N	-	Normal force perpendicular to the tool face

Greek letters

α	-	Effective rake angle
α_b	-	Back rake angle.
α_n	-	Normal rake, oblique rake or primary rake
α_s	-	Side rake angle
α_v	-	Velocity rake or true rake.
β	-	Friction angle
Φ_c	-	Rate of heat transportation by the chip
Φ_l	-	Rate of heat dissipated by others
Φ_t	-	Rate of heat conduction into the tool
Φ_w	-	Rate of heat conduction into the workpiece
ϕ	-	Shear angle
ϕ_n	-	Normal shear angle
γ	-	Shear strain
γ_n	-	Shear strain normal to the cutting edge
η_c	-	Chip-flow angle
η_s	-	Shear flow angle
μ	-	Coefficient of friction
σ	-	Normal stress
τ	-	Shear stress, shear strength of the welded asperities

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